NEDA – Neutron Detector Array

5th LEA-COLLIGA Meeting , IPN-Orsay, 14-16 November 2011
On behalf of the NEDA collaboration

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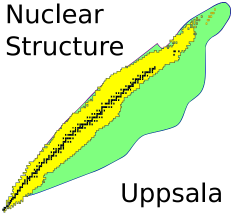

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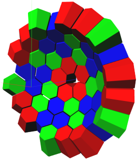
Outline

Aim and strategy of the NEDA project

Aim



- Develop and build a neutron detector array to be used with AGATA, EXOGAM2, GALILEO, PARIS for experiments with high-intensity stable and radioactive ions beams at SPIRAL2, SPES, ...
- The array should have:
  - Excellent neutron-gamma discrimination.
  - Increased efficiency to detect ≥ 2 neutrons: $\varepsilon_{2n} = 5\text{-}10\%$ (Neutron Wall: 1-3%).
  - Capability to run at much higher count rates than with the Neutron Wall.
  - Cope with large neutron multiplicities in reactions with neutron-rich RIBs.
  - Improved neutron energy resolution for reaction studies.

Strategy

- Optimize size of detector units, distance to target, geometry of the array, ...
- Investigate other detector materials than ordinary liquid scintillator: deuterated liquid scintillator, solid scintillators.
- Adopt digital electronics which is fully compatible with AGATA and EXOGAM2.
- Develop advanced on-line and off-line algorithms for neutron-gamma discrimination, neutron scattering rejection, pile-up rejection/recovery.

Organization

Spokesperson

J.J. Valiente Dobon (LNL-INFN)

FP7-Infrastructures-2007-1
SPIRAL2 Preparatory Phase

GANIL liaison

M. Tripon (GANIL)

FIRB
Futuro In Ricerca (MIUR)

Steering committee

N. Erduran (Istanbul), A. Gadea (Valencia), J. Nyberg (Uppsala), M. Palacz (Warsaw), L. Stuttgé (Strasbourg), R. Wadsworth (York).

NEDA Collaboration

Ankara University (Turkey), COPIN (Poland), CSIC-IFIC (Spain), Daresbury Laboratory (UK), GANIL (France), Istanbul University (Turkey), INFN (Italy), IPHC (France), Nide University (Turkey), University of York (UK), Uppsala University (Sweden).

Working groups

Detector characteristics and physics

Bob Wadsworth

Simulations and conceptual design

Marcin Palacz

Study of new detector materials

Louise Stuttgé

Front-end electronics and DAQ

Andres Gadea

Pulse-shape analysis

Johan Nyberg

Synergies with other detectors

Piotr Bednarczyk

Physics with NEDA

Studies of proton- and neutron-rich nuclei

- Nuclear Structure
  - Probe $T = 0$ correlations in $N = Z$ nuclei: the structure beyond ^{92}Pd (GANIL, LNL, Stockholm, Uppsala, York)
  - Coulomb Energy Differences in isobaric multiplets: $T = 0$ versus $T = 1$ states (GANIL, LNL, Warsaw, York)
  - Coulomb Energy Differences and Nuclear Shapes (GANIL, Padova, York)
  - Low-lying collective modes in proton-rich nuclei (Istanbul, Krakow, Milano, LNL, Valencia)
- Nuclear Astrophysics
  - Element abundances in the in-homogeneous Big Bang Model (GANIL, Soreq, Weizmann)
  - Isospin effects on the symmetry energy and stellar collapse (Debrecen, Florence, LNL, Naples)
- Nuclear Reactions
  - Level densities of neutron-rich nuclei (Florence, LNL, Naples)
  - Fission dynamics of neutron-rich intermediate fissility systems (Debrecen, GANIL, LNL, Naples)

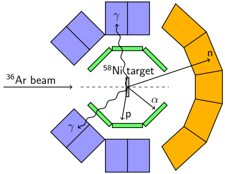
^{92}Pd experiment at GANIL

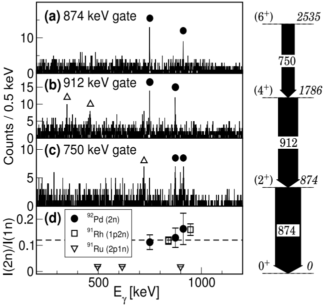
Experiment at GANIL (2009)

EXOGAM + DIAMANT + Neutron Wall (50 liq. scint.)

^{36}Ar (111 MeV) + ^{58}Ni $\rightarrow$ ^{92}Pd + 2 n

Cross section: $\sigma_{\text{fus}} \sim 0.2$ b, $\sigma_{^{92}\text{Pd}} \sim 1\mu$b

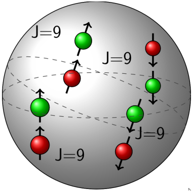




First observation of excited states in ^{92}Pd

Approximately equidistant energy levels

Valence neutrons and protons couple pairwise to $S = 1$, $T = 0$ in the ground and first excited states of ^{92}Pd



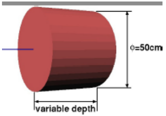
B. Cederwall, F. Ghazi Moradi et al., Nature 469 (2011) 68

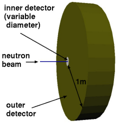
Approved GANIL experiment (14 days) to study ^{96}Cd.
Spokepersons: B. Cederwall, G. de France, R. Wadsworth)

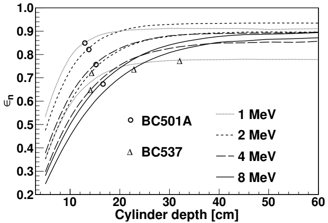
GEANT4 simulations, optimal size of detector units

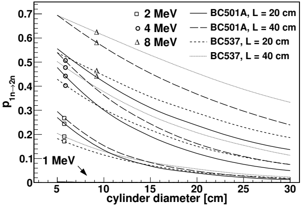
G. Jaworski, M. Palacz (Warsaw)

GEANT4 validated for simulations of interactions of fast neutrons with energies up to about 10 MeV in liquid scintillators.









Optimal depth: $\sim$ 20 cm

Optimal diameter: 5" (PMT)

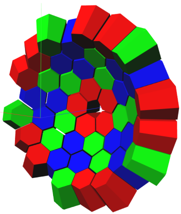
G. Jaworski et al., submitted to Nucl. Instr. Meth. A

Conceptual design and geometries

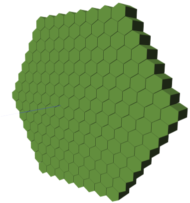
T. Hüyük (Valencia)

Two possible detector geometries: tapered, planar

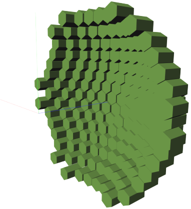
Tapered: spherical
(1π, 0.5 m, 45 cells, 203 l)



Planar: flat
(0.4π, 1.0 m, 169 cells, 507 l)



Planar: staircase
(0.9π, 1.0 m, 164 cells, 489 l)

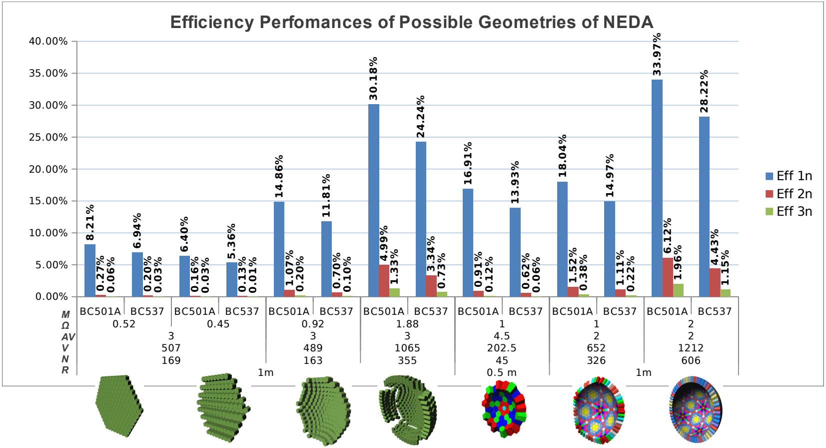


Tapered: easy coverage of $>1\pi$ of the solid angle with "few" cells.

Planar: flexibility regarding different arrangements of the detectors and the target-detector distance.

Simulated neutron efficiencies for different geometries

T. Hüyük (Valencia)



R	Distance from the origin / Radius (meter)	Simulated neutron source:	Cf-252
N	Granularity (Number of modules)	Depth of the detectors:	20 cm
V	Total Volume (liter)	Neutrons were shot in 4π solid angle	
AV	Average Volume (liter)	1E+7 statistics have been recorded	
Ω	Solid angle coverage (π)		
M	Material		

New detector materials and light readout techniques

New detector materials

- Deuterated liquid scintillator (BC537).
- Solid scintillators: IPHC Strasbourg (Le.. Stuttgé), LLNL, Dubna

Novel light readout technologies

Main aim:

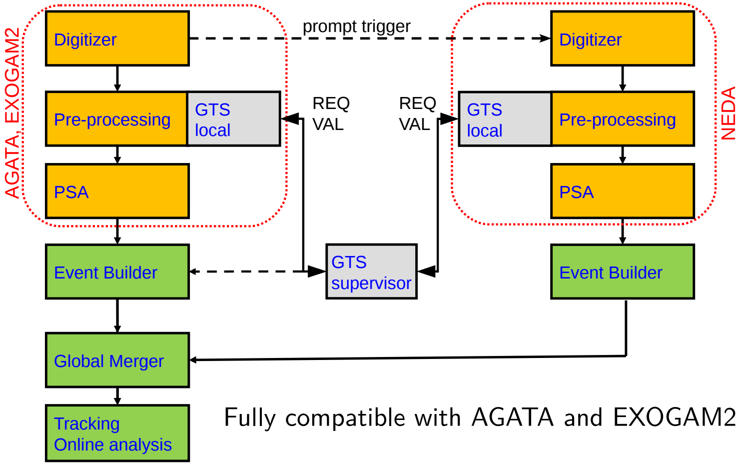
- Larger quantum efficiency (QE) than ordinary PMTs ($\sim 20\%$).
- Position sensitivity.

Under evaluation:

- Super bi-alkali PMTs: QE up to $\sim 40\%$.
- Avalanche Photo Diodes: QE up to $\sim 80\%$, size few cm^2.
- Silicon PMs, size few cm^2.

Front-end electronics and data acquisition

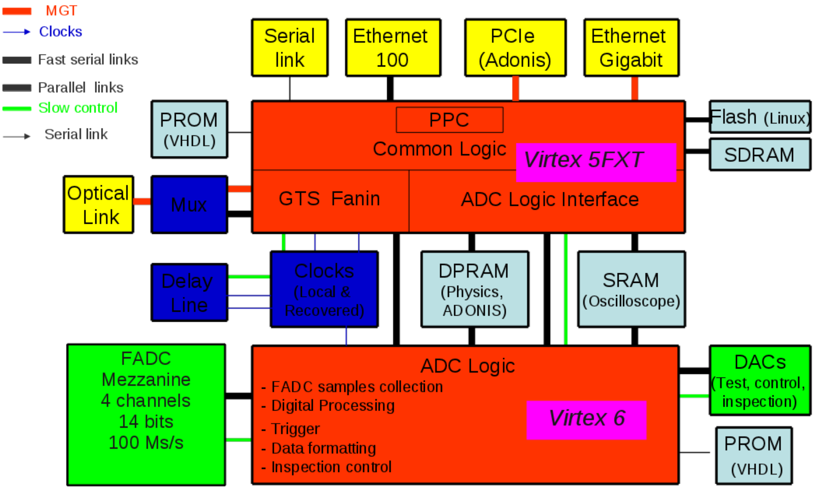
Developments by GANIL and Valencia.



Fully compatible with AGATA and EXOGAM2.

NEDA digitiser – carrier board

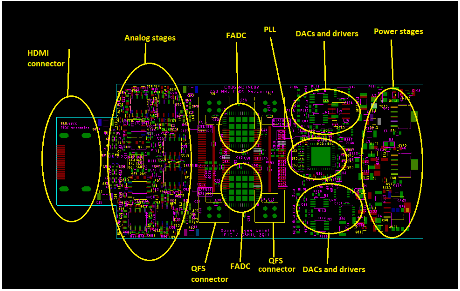
Developments by GANIL and Valencia.

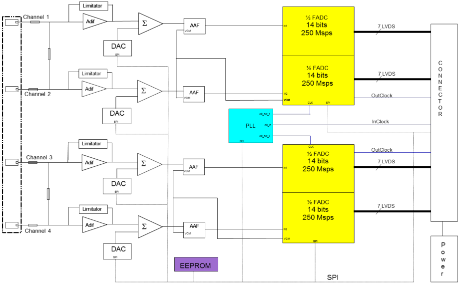


NEDA digitiser – FADC mezzanine

X. Egea (Valencia).

- 4 channels per mezzanine.
- Sampling rate 250 MS/s, 14-bit resolution.
- 6 W power consumption.



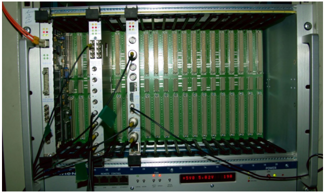


- Carrier board dimension with NIM standard.
- 4 FADC mezzanines per carrier board.

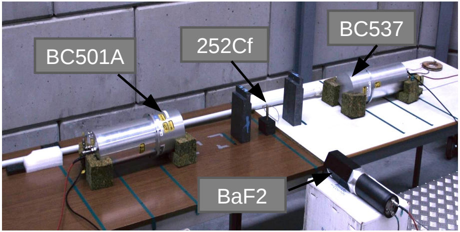
Test measurements at LNL 2011

Instrumentation:

- Cylindrical 5" × 5" prototype liquid scintillator detectors
  - 2× BC501A (C_8H_{10})
  - 2× BC537 (C_6D_6)
- ^{252}Cf source with BaF_2 detector as time reference for TOF measurement.



- Digitisers:
  - SIS3302 8 ch, 100 MS/s, 16 bits
  - SIS3350 4 ch, 500 MS/s, 14 bits
- VME-based DAQ by J. Agramunt (Valencia)



Performed tests:

- Neutron-gamma discrimination
- Neutron efficiency measurements
- Neutron scattering measurements
- Leading-edge timing

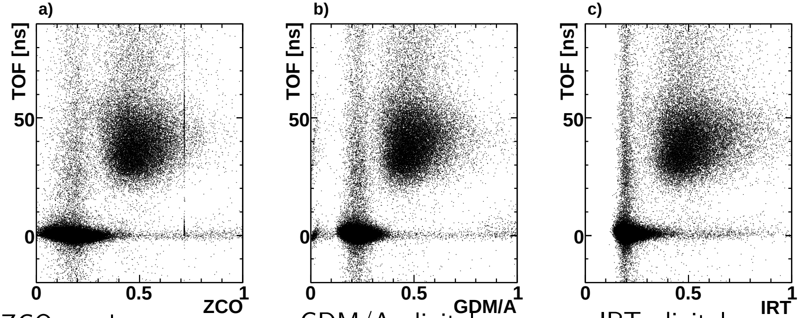
Analysis in progress . . .

Todo:

- High count rate tests (pileup)

Neutron-gamma discrimination with digital electronics

Earlier work: *P.-A. Söderström et al., Nucl. Instr. Meth A 594 (2008) 79.*



ZCO: analogue zero-crossover

GDM/A: digital charge comparison

IRT: digital integrated rise time

Conclusions from this work:

- Digital pulse-shape analysis works as good or better than analogue ZCO for neutron-gamma discrimination.
- Digitiser: sampling frequency $\geq$200 MS/s, number of bits $\geq$12.

Neutron-gamma discrimination with neural networks

Earlier work on neutron-γ discr. with artificial neural networks (ANN):

E. Ronchi, P.-A. Söderström et al., Nucl. Instr. Meth A 610 (2009) 534.

Better neutron-gamma discrimination than with “standard” digital PSA methods, in particular for small signals.

Tests performed at LNL 2011

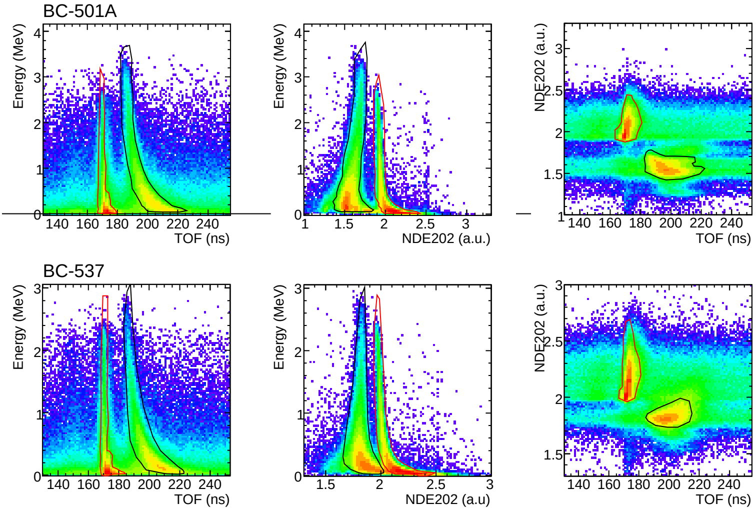
Analysis by P.-A. Söderström (Uppsala).

Type of ANN:

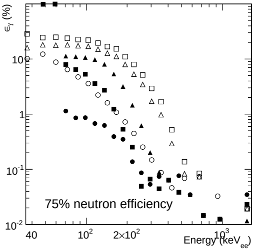
- A feed-forward ANN based on the ROOT `TMultiLayerPerceptron` class.
- 75 input nodes, corresponding to the first 75 sampling points.
- Two hidden layers of 20 nodes and 5 nodes, respectively.
- One output layer where the value 0 corresponds to a γ ray and the value 1 corresponds to a neutron.

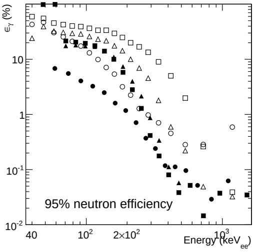
Training of the ANN

- The network was trained using 50000 train and 50000 test entries.
- Neutrons and γ rays were identified using analogue ZCO-TOF-Charge cuts.



Preliminary results





Gamma rays mis-identified as neutrons

- y-axis = fraction of γ rays identified as neutrons.
- x-axis: energy deposited in the detector in units of keV$_{ee}$ (keV electron-equivalent).
- Top (bottom) figure: 75% (95%) of the neutrons remain after neutron-gamma discrimination.
- Filled (open) symbols: BC501A (BC537)
- Digital neutron-γ discrimination methods:
  - Circles: Artificial neural network
  - Triangles: Integrated rise-time
  - Squares: Charge-comparison

Conclusions

- ANN is best in particular at small energies
- BC501A is better than BC537

Preliminary results

Phases of NEDA

Current plan is to build NEDA in four different phases 2012-2015:

Phase 0

Upgrade of the Neutron Wall to use digital electronics.

Phase 1

Construction of the NEDA Demonstrator with a limited size.

Phase 2

Construction of the full NEDA array.

Phase 3

R&D on new detector materials and light readout systems for a highly segmented neutron detector array.

NEDA Memorandum of Understanding

Purpose of the MoU

Specify what the Parties of the MoU intend with respect to planning, funding, constructing and operating of NEDA.

The MoU will be a non-binding expression of the current intentions of the Parties.

Time schedule

- December 2011: steering committee meeting to finalize the MoU.
- Early 2012: signing of the MoU.

Summary and outlook

- NEDA will be the next generation neutron detector array to address the physics of neutron- and proton-rich nuclei, mainly in conjunction with γ-ray spectrometers like AGATA, EXOGAM2, GALILEO, and PARIS.
- Verification of GEANT4 simulations $\rightarrow$ size of detector units.
- GEANT4 simulations of NEDA geometry.
- Development of electronics in synergy with EXOGAM2.
- Ongoing tests of BC501A and BC537:
  - Digital PSA neutron-gamma discrimination.
  - Neutron efficiency.
  - Neutron scattering.
  - Leading-edge timing.
- Future R&D of new materials and large area APDs.
- NEDA will be built in phases 2012-2015.
- MoU to be signed early 2012.

Thank you

Acknowledgments to all members of the NEDA collaboration.